ESD-TR-67-204

# DECISION SCIENCES LABORATORY BIENNIAL PROGRESS REPORT (TERMINAL REPORT) for the period July 1964 thru June 1966

OCTOBER 1966

DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts, 01730

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FOREWORD

This is the Final Biennial Progress Report of the Decision Sciences Laboratory. On 20 June 1966, it was announced by Maj. Gen. J. W. O'Neill, Commander of ESD, (AFSC), that the laboratory was to be abolished because of Command-wide reductions in manpower authorizations and the comparatively low priority of the program of the laboratory in the Electronic Systems Division. The effective date of the dissolution is 1 April 1967. This Technical Report has been reviewed and is approved.

Roy Morgan

ROY MORGAN, Colonel, USAF
Director, Decision Sciences Laboratory

ABSTRACT

This report, covering the period July 1964 through June 1966, describes the exploratory development work performed by the Decision Sciences Laboratory in the areas of data presentation and display, communications testing, problem solving, and automated training.

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## HISTORICAL NOTE

### History

The Decision Sciences Laboratory, an Air Force in-house laboratory since 1948, was involved in planning, conducting and monitoring basic and applied research throughout its history. The major emphasis in its mission and program was to look ahead, to carry on research aimed at providing avenues to fill important gaps in the knowledge about people, particularly in information systems kinds of tasks, intended always to improve the capability and effectiveness of the Air Force.

In 1948, assigned to Hq USAF, it was designated the Human Resources Research Laboratory. In late 1952 it was transferred to the Air Research and Development Command along with other AF human factors organizations and its name was changed to Human Factors Operations Research Laboratory and it was tasked, in addition to its programs in basic-applied research in human information processing, with human engineering and personnel studies supporting AF operational commands. In 1954, the Laboratory was re-organized as the Operational Applications Laboratory and was assigned as a laboratory in the Air Force Cambridge Research Center. The mission involved human factors research in communications and information processing, and human engineering and systems analysis studies.

In 1961 with the re-organization of ARDC and the formation of the AF Systems Command the laboratory was assigned to the Applied Research Division of the Deputy for Technology, AF Command and Control Development Division with its mission unchanged. With the organization of the AF Electronic Systems Division the Laboratory was then assigned at the directorate level to the Deputy for Engineering and Technology, ESD, as the Decision Sciences Laboratory.

Throughout its history the laboratory maintained a viable, productive research program responsive to Air Force needs and centered about "human information processing behavior."

## ABOUT THE DECISION SCIENCES LABORATORY

### General Definition

The Decision Sciences Laboratory (DSL) is a behavioral sciences laboratory especially concerned with the behavior of man in complex military environments involving the presentation and processing of information. It is a laboratory whose main function is exploring, defining, and effecting the most efficient interaction between man and machines in military information systems. Such systems are sophisticated computer based electronic systems which gather and process huge quantities of data, and present information to military commanders and controllers which they then use as aids in decision-making. These systems are currently in use or are anticipated by many United States Air Force and related Department of Defense agencies.

DSL is an Air Force organization of 37 individuals,directed by an Air Force officer, and its mission is wholly military. It is unique among military organizations, however, in that the professional staff is 85 % civilian. Most scientists on the staff are psychologists, but there are also electronic and mechanical engineers, mathematicians, psycholinguists, and operations analysts. The academic achievement of staff members is in almost every case well beyond the Master's degree. Nearly 50% have the doctorate.

In the military organizational structure, DSL is a component of the Electronic Systems Division (ESD), and is directly responsible to the Deputy for Engineering and Technology. ESD and several related facilities which contribute to its mission form the complex of technological activities at and around L. G. Hanscom Field, Bedford, Mass. Roughly 8,000 people are employed by ESD, which is a major branch of the Air Force Systems Command (AFSC), one of the major Air Force commands.

## Mission

The Decision Sciences Laboratory initiates exploratory development programs. That is to say, it estimates and examines future operational requirements of the Air Force, especially in the area of information processing systems, and determines from these investigations what problems are implied for the interaction of man and machine. Attempts to fill critical gaps in knowledge about human performance and machine design which thus come to light are made through exploratory development projects under each program. Most of the experimental work on these projects is conducted at the laboratory, although it is sometimes expedient to carry on certain portions through contracts negotiated with particular industries or academic institutions where critical or otherwise unavailable facilities can be utilized. DSL is also responsible for designing, developing, procuring, evaluating, managing, and updating certain display components of Air Force information systems. Further, it provides engineering services to all elements of ESD in the areas of its professional competence, e.g., display characteristics, human performance, and man-machine relationship problems, for both the present and future information system needs.

So there is a continuum of scientific activity underway at DSL. Exploratory development projects sometimes investigate the most abstruse and seemingly insignificant of quantifiable variables in human behavior. But such studies contribute to the growing body of knowledge which is the condition of activity at the other end of the continuum ---applications, or the direct support of efforts in the "real world" of computerized command and control environments.

## Philosophy

The paraphrase of the formal mission statement above only barely suggests the import of DSL's potential for electronic systems design technology.

In general. In its present state of development, the technology is very advanced in the production of sophisticated hardware — computers,

radars, and so on. The state-of-the-art is advancing rapidly as concerns software — programing computers and developing other means by which to use the equipment more effectively. But it is embryonic in its comprehension of how man can most efficiently function as an integral part of these systems — in knowing how he uses the information supplied him to make decisions, in recognizing the effects of information displays on decision-making behavior — in comprehending, in short, how men and computers interact.

In particular. In the Decision Sciences Laboratory, ESD possesses a unique professional and technical potential in a most critical part of total system design, namely in defining man's part in the system. Electronic systems are merely hardware — impressive, maybe, but little more without their human users. Total electronic systems include people. More accurately, in the complex of dove-tailing events from a radar sensor's detecting physical phenomena through the computer's collecting and analyzing data about them, to man's choosing one from many possible courses of action, man is the most important factor. He is most important in two ways. 1) Man has the "last word." He is the agent who must effect the appropriate decision after sensors and computers have collected, processed, and presented data about, say, an attacking enemy force. That decision may have very far reaching consequences indeed. 2) Very little is known about the human element in the pressures of a multi-machine information system environment, about man's behavior as he operates such complex equipment, evaluate a complex military situation, assumes the roles of commander and controller, and ultimately makes an involved decision. These functions, along with the most "human" of all man's capabilities — improvisation, inventiveness, imagination, can doubtless never be duplicated electronically.

So we must make the most efficient use of this most important part of an information system — man — and make it easier for him to bring his unique capabilities to bear on complicated problems. To do this, we must

learn a great deal more about him than we now know. What processes underlie his very long-term memory for material which would take literally millions of binary bits to describe electronically? What data does he use in selecting alternative actions? How does he weigh and manipulate these data? How much data can he be expected to evaluate? How fast? What form should the data take to be most useful to him, and thus to the system mission? The answers to these and many similar questions are vital, both in specific, concrete situations in the "real world" and in more general theoretical settings, not only so we can better use man in military systems, but so we can better understand man himself. The technical program at the Decision Sciences Laboratory exists in order to answer these and similar questions about man as the modern military commander, controller, and information processor, and about man in his own right so that it can design and develop machines to serve him better.

<u>Condition of Effective Operation</u>

Finally, a word should be said about how DSL must proceed in order to hope to realize any of the goals embodied in its philosophy. The ability of DSL to make significant contributions to systems, either in the design or operational stages, is entirely dependent on its being involved in research which is in the context of total system design. That is, in order that the findings of research might have direct application, be useful here and now in information systems, the laboratory staff must be aware of the direction and extent of progress in all other related technological areas. Only by this means can it direct and advance its own research so as to advance the whole state-of-the-art purposefully.

<u>Tri-National Symposium on Information Presentation</u>

There are many avenues to keeping in touch with the advancing state-of-the-art. Probably the most direct is to be actively involved in the design and modification of systems in the field. But the exchange of views

in a more detached atmosphere is equally vital. DSL scientists participate regularly and frequently in professional conventions of many sorts, and recently initiated a medium for exchanging information which perhaps uniquely meets its needs. This is the Tri-National Symposium on Information Presentation, intended as an annual meeting of behavioral scientists and professionals in related idsciplines from France, Germany, and the United States. One of the purposes of such an international symposium is to exchange views on the human-factors aspects of information presentation, which is the sole purpose of displays — to inform their users. It is aimed at understanding and coping with the problems associated with the respective roles of man and the machines that support him. A general summary of the symposium held in October of 1965 follows.

Presentations made by the French participants focussed on the areas of physiology and psychological stress and on the application of ergonomic work study methods in analysis of operator performance in air-defense environments. These provided some novel insights into factors in automated data presentation such as effects on the rest-work cycle on alertness and the stability of meaning of different levels of abstraction in symbolic coding as a function of the pressure of the job at hand. The "re-engineering" of display equipment for Naval Tactical data was also described as were a proposed performance evaluation in the STRIDA air defense system. Of major interest here were the actual and proposed methods.

The German delegation concentrated in the area of display for the control of vehicles, mainly vertical take-off and landing aircraft (VTOL) but including ships. Some really pioneering work was presented on combinations of two dimensional display for the three-dimensional problem of "hovering" a VTOL and on "predictive" displays to facilitate pilot control prior to and during the very extreme transition between vertical and horizontal flight and vice versa.

United States presentations were concentrated in the areas of computer generated display. One major area involved new developments in computer input and output for direct, on-line interaction between operational user and machine (the SDC General Purpose Display System and the Decision Sciences Laboratory statistical processing programs). Another major area was that of character display - a new system for specification of requirements for legibility and the effects of TV scan resolution on character quality. The U. S. also provided presentations on display for vehicular control (The Rainbow Landing System) and a proposed development of models of data organization as a function of decision task-in-hand for purpose of guiding display developments.

The concensus of attendees has been that several valuable purposes were served by this symposium. There was a very effective exchange of information in all directions. Each nation transmitted and received valuable data to and from others that would not otherwise have been exchanged. Representatives of the three countries also engaged in many informal discussions, giving and receiving unpublished advice and benefit of experience. In addition, professional contacts in the different areas of specialization were established which will continue to bear the fruit of cross-fertilization and international cooperation for years to come.

## PROJECTS

The projects which DSL has been pursuing for some years are aimed at fulfilling certain present and future operational needs of the Air Force. DSL's professional staff identify and define the problems to be solved by examining the Technical Objectives (TO's) which specify the entire range of the Air Force's operational requirements. The laboratory staff searches those areas likely to contain problems it is uniquely competent to tackle and considered relevant to the mission of ESD, areas such as human performance, computer and information processing techniques, intelligence techniques, and communications. As the outline of mission requirements states, the

procedure is to analyze from the TO's implications for man-machine integration, and to identify critical gaps in the knowledge about human performance which come to light. Once a need is identified, the problem of meeting it is attacked through an exploratory development project which is directed by one of the laboratory's division chiefs. This scientist is responsible for initiating the project, for justifying it in terms of Air Force needs, for specifying the objectives and the approach, for subdividing it into a number of workable tasks, for estimating cost and manpower requirements, and obtaining ESD approval for its exploitation. Thereafter, he is responsible for its general administration, and for documenting its progress in terms of solution of the overall problem.

Project Titles

From an administrative point of view, DSL's total effort is currently organized under and channeled toward completing three projects and one task which is part of a project managed by another activity. These are (1) Project 7682: "Man-Computer Information Processing," (2) Project 2806: "Dynamic Man-Computer Interaction," (3) Project 2808: Psycho-acoustic Standards in Voice Communication System Evaluation," and (4) Task 280111: "Communication with Computers in English."

Nature of the Projects

Each project embraces an area approaching a main branch of the science, and outlines only in the most general terms the major objectives. Even the tasks into which each is divided are major efforts, and are further broken down into numerous studies and experiments. As one study is completed, another will be planned based on the conclusions of the first. Occasionally a series of experiments will suggest a new field of inquiry, and a new project will be split off from the old one. On the other hand, as tasks progress toward completion, several projects will be incorporated into one. Thus the projects undergo a slow process of evolution. They are continuing in nature and have no specified completion dates.

The projects themselves do not mutually exclude one another. Much of the experimental work is directly relevant to two or more projects, all of which are directed toward a quantifiable description of human behavior. Studies of human information processing, for instance, have real meaning for all of the projects. On the other hand, the projects are not intended to represent the whole continuum of psychological inquiry. They are designed, as was previously suggested, to fill system needs which are evaluated as being pressing.

For all these reasons — the breadth of the projects, their evolutionary nature, and the fact that they do not exclude one another — it is difficult to conceive of DSL's effort in terms of work completed under a given project. One should consider a project as an administrative necessity and convenience.

## BIENNIAL PROGRESS

The projects listed in the previous section have had complicated histories during which new tasks have been incorporated and original ones terminated. The result is that some work carried on under one formal project could quite logically be justified as being part of another. So rather than listing research under its respective project, this section on progress is divided into research areas which will be more meaningful to readers not thoroughly familiar with the specific intent of each project.

### Classification of DSL's Effort

There are six research areas into which the whole spectrum of DSL's output can be conveniently divided: (1) data presentation and display, (2) learning, problem solving and decision-making, (3) programed teaching and automated training, (4) communications, (5) applications, that is, studies and consultant services in direct technical support to planned and existing systems, and (6) support services to DSL's automated laboratory facility. In this section each area is described. The description is followed by a bibliography of reports and papers, having meaning for the area, completed during the period from July 1964 through June 1966.

Bibliographies

A few entries in the bibliography sections which clearly have relevance to two areas are included twice. Most entries have been given ESD Technical Report numbers (TR's). Most of those that do not are unpublished papers read at professional meetings or working papers for use inside the laboratory. DDC numbers reflect Defense Documentation Center control for requesting the reports.

Purpose

The purpose of this section is to indicate concretely the nature and scope of DSL's effort, and to list the results for the record. It is designed as a listing of research completed since the publication of Bibliography of Human Factors Research with Abstracts, 1954 through 1962, (ESD-TDR-63-603), and Decision Sciences Laboratory Biennial Progress Report, July 1962 through June 1964 (ESD-TDR-64-609).

Data Presentation and Display

Because the effectiveness and reliability of today's complex semi-automated information systems depend so heavily on the man involved, we must describe and measure his information processing behavior as precisely and completely as possible. Such behavior is the composite of a number of closely related processes which have been isolated from one another, to as great an extent as possible, so that each can be measured individually. One such process — the first in the related events which result in a decision — is the way man perceives and stores information.

Objective. The purpose of studies in data presentation and display, then, is to quantify the variables which affect perception and retention so that it will be possible to specify the particular display features which man can best use in any particular information processing task. DSL scientists seek to be able to specify what sizes, colors, and shapes of symbols, letters, numbers and other coding techniques are best for transmitting data, and what kinds and amounts of data to present so that man can transform them into meaningful information effectively.

Approach. Studies in perception are generally approached by manipulating quantifiable display characteristics, and then measuring the effect of such manipulation on man's ability to detect or identify signals. But the apparently clear cut problem is complicated by at least two factors. First, it has always been extremely difficult to say where man's perception of data stops and his processing of them begins. Second, as displays become increasingly complex, the scope of the research effort is being extended to include the increasingly complex effect of "display interpretability," which here refers to consolidating, integrating, and evaluating information, and not simply to detecting it and measuring the legibility of the display itself.

Progress. As suggested earlier, perception, memory, decision-making, and problem solving are all integral parts of information processing, and achievements in one area will unquestionably benefit research in other areas. However, the descriptions of research projects which follow seem to have relevance primarily for data presentation and display.

(1) Experiments are complete in which investigators proposed to determine subjects' ability to recognize geometric forms of varying complexity. Both the degree of complexity and time lag between the first and second appearance of each figure was varied and the effect measured. As a result, a statement can be made concerning the degree of complexity which might be effectively incorporated into any non-verbal display.

(2) An extensive series of experiments to establish the range of visual search has been completed. These experiments were undertaken to determine the manner in which man scans displays and searches for information under a number of varying conditions. DSL has gleaned a great deal of useful information from these experiments about, for example, search pattern shapes, optimal numbers of elements in a stimulus matrix, matrix size as it varies with man's exposure to it, and the value of subdividing matrices.

(3) Experiments are planned to investigate the relative virtues of flat versus hemispherical map displays. Tentative decisions about design of the apparatus and variables to be manipulated have been reached. If hemispherical displays prove to have distinctive advantages, in terms of target specification, there would be an obvious improvement in the effectiveness of information systems which display large portions of the earth's surface because present Lambert Conformal projection maps are necessarily distorted. This research and its results are of considerable interest to NORAD, for display of subsatellite trajectories.

(4) The users of information systems are frequently faced with a plethora of information which they must then sift through and select what they need. Data presentation and display scientists are taking two approaches to the problem, neither of which has been adequately explored. First, experiments are being conducted in which computer display texts are presented in novel ways to facilitate reading efficiency. Second, DSL is working toward improving the reading efficiency of man himself by using a simple reading pacer and ordinary texts, and experimenting with pacing the reader in chunks of a paragraph or more.

(5) The status of research on readability was assessed. It was concluded that until investigators grapple with criterion problems more effectively, improved readability predictors are highly unlikely.

(6) A study comparing the readability of electroluminescent versus teletype displays for weather messages was conducted. The mostimportant results of the study were specific recommendations for improved processing of weather information, and possibly for improved processing of information for other military systems. In addition to display problems it is suggested that some operators are "error prone" thus reducing system effectiveness. This factor should be investigated.

(7) On the applications end of the research spectrum, DSL scientists contribute to the ESD Technical Monitor Program as display consultants in advanced planning studies. DSL is represented in the Display Working

Party of the Joint Technical Coordinating Group/Tactical Air Control System, which reviews programs in all three military services. This review will consist of an evaluation and identification of programs that have application to TAC, to increase the effort in those areas where warranted, initiate programs when found necessary, delete duplication and combine programs where deemed desirable. DSL scientists also provide display consultations to users of existing systems such as the National Military Command Center and to numerous System Project Offices. (<u>See Applications</u>).

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Learning, Problem Solving and Decision-Making

After man detects displayed information, he must store it and later retrieve and process it in order to solve problems and make decisions. The behavioral sciences seek to enhance the processes of storage and retrieval and consequently the operations involved in problem solving and decision-making. Many questions are generated by such investigations, the many answers to which are only barely tentative, and in attempting to arrive at valid conclusions, human factors scientists are forced to investigate extremely complex intellectual processes. The vast amount of scientific research literature focused on the problems of how information is processed does not in all cases apply specifically to information system problems. Typically, such problems are compunded by the pressures of an information system environment: the need for a number of people to confer and reach quick decisions on important issues. Researchers, therefore, must tease out what often appear to be minor and unimportant bits of knowledge. These units eventually can be integrated so that explicit answers to the questions created by these complex situations can be stated.

Objective. Ultimately, we must be able to answer the question, "what is the most effective method by which man can process information and make decisions in a dynamic, time-constrained, multiple-choice situation in which the task is vital and the environment stressful? More particularly, DSL's objective is investigating the particular aspects of man's information processing behavior which should be at an optimum level even while working under pressure in an information system environment.

Approach. As in studies of data presentation and display, the approach is to specify and quantify as precisely as possible the myriad of variables which could conceivably affect man as he stores information, solves problems, and makes decisions, especially under stress. DSL attempts to

simulate these complex conditions so that experimental studies can be made of the relevant variables. These variables, such as experience levels of operators and decision makers, levels of complexity of the tactical situation, various levels of work load, amount of accessible pertinent information, and uncertainty of outcome must be manipulated to specify their optimum values and ultimately to establish conditions for the most effective dynamic decision-making.

Progress. Some of the very important work accomplished in the field of lear ning, decision-making and problem-solving can be indicated here.

(1) Because the information system environment is stressful, an effort is currently underway to ascertain some of the effects of speed-stress in processing information from a visual display.

(2) The information system operator is required to recall, at random intervals, information which he has been storing while he continues to process new information. Special short-term memory experiments have been designed which apply specifically to this kind of activity. A study completed in 1964 showed that processing a query during continuous short-term memory activity significantly degrades recall more than does processing an intervening message. During the course of this study, it was concluded that the rate and accuracy of acquiring short-term memory data could be improved by using some recent decision theory techniques. A study to test this hypothesis was subsequently completed which yielded considerably improved performance measures.

Another study demonstrated that short-term memory may be of greater capacity than was previously realized. Individuals inspected extended sequences of complex but meaningful visual configurations, and decided whether each was occurring for the first or second time in a series. They were able to identify stimuli correctly significantly greater than chance even when as many as two hundred items intervened between the first and second

appearances of an item. The study was extended to investigate the ability to recognize pictorial material after delays of up to one year between initial and subsequent exposure to the item. Even with this extension the subjects were capable of correctly recognizing pictures at a level greater than chance.

(3) Series of experiments in the general area of verbal learning have been going on for some time. These have to do with man's ability to recall or recognize verbal series and to retrieve words from them, activities which are similar to those required of information system personnel. One study measured the effect of length of verbal series on recall, and the results suggest possible information retrieval strategies. Another yielded specific information on the influence of word-frequency on serial learning. Still another examined the effect on recall of long series of words which could be assigned to semantic categories such as birds or animals. The effects of varying such factors as the number of categories and the number of members in each category were measured, and the results could have significant meaning for future coding techniques in displays. A study was undertaken to test the theory that typical items in the middle of a series (where learning is usually more difficult) will increase the probability of such items being recalled. The study did in fact substantiate the theory, and may have implications for design of future information system display materials.

(4) One of the unique features of the information system environment is that decisions are often made by teams of men working together. Thus it is vital that we know reliably the extent to which the whole range of decision-making behavior (from detecting information to making a decision) may be modified by characteristics of the individuals and by social or personal influences operating in a group. The group factor enormously complicates the problem of specifying optimum criteria for information system decision-making, and has generated extensive investigations of group performance which have been going on for some time. The experimental work is

concerned with input processes in small groups: vigilance, pattern detection, storage and transmission of information, etc. The research is inquiring into the reciprocal influence of group members under different conditions of task difficulty. Further it is vital to know reliably the extent to which all types of decision-making behavior may be modified by the characteristics of the individuals and by the social or personal influences operating within task-oriented groups. Several reports have been completed and several experiments are still in progress.

(5) DSL recently evaluated a series of proposals and granted a research contract, the goal of which was the specification of Air Force weather forecasters' decision-making processes in the field. The research is aimed at identifying the large number of variables operant in weather forecasting, and may ultimately lead to defining the optimum variable complex for decision-making strategy for forecaster accuracy.

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for

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Remove pages 23-24 and insert this corrected page.

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Programed Teaching and Automated Training

As information systems become more complex, advanced, and capable of processing more information in less time, it becomes increasingly difficult for users — commander, controller, operator, and maintenance personnel — to exploit their potential and to keep them operating efficiently. In other words, the very features which make information systems potentially more useful also curtail their usefulness by putting added burdens on the people who work with them. Paradoxically, the time required to learn how to perform the new and complex intellectual and perceptual tasks tends to negate the value of the improved hardware.

Objective. By way of working toward a solution of this "training dilemma," DSL is carrying on vigorous research in programed teaching and automated training. This is an attempt to provide the kind of on-site training materials necessary for establishing and maintaining proficiency in using sophisticated electronic equipment. But the need for devices which expedite the learning process does not end with computer operators. People in many jobs requiring that a man perform complex tasks or make involved decisions can benefit from programed teaching. Courses, for example, have been developed for teaching managerial techniques such as PERT, described below, and many of the design principles evolved from research for command and control system courses have been incorporated in them.

Although the training courses are different (some are computer programs and some are text books), and although their methods differ widely, they all have much in common. All are tutorial courses designed to minimize the need for a human teacher. They teach, test learning, reteach if necessary, and maintain proficiency at a level required by the job. They lead the learner by very judiciously selected increments, called "frames," to the learning goal. The theory is that such a process will save time in the long run by preventing the learner from forming misconceptions which would block the ultimate learning goal.

Specific objectives include (a) developing principles for designing the hardware and software for self-instructional courses, (b) developing working models for presenting information in programed instruction, programed practice, and programed laboratory sequences tailored to the many different skills which information system users require, (c) developing automated techniques for design, construction, evolution, and evaluation of the programed materials, and (d) analyzing problems associated with implementing automated training in the field.

Approach. Because the need is pressing, research in programed instruction and automated training is being carried on throughout the whole continuum of DSL's mission effort, that is, in exploratory development projects, in special tests and studies, and in direct support of planned and existing systems of many types.

More specifically, DSL has taken two related approaches toward developing teaching techniques. The first has concentrated on defining the self-instructional features required in courses dealing with the many different duties at the information system console. During the studies of typical users consoles, investigators found that only a few simple additions would allow these consoles to serve as part time teaching machines. This led to the second approach which was to adapt certain aspects of operational computer programs to the training function. Experimental models for self-instructional computer programs have been successfully developed.

Progress. The many resulting studies have yielded the laboratory reports included in the bibliography. In turn, the experimental and conceptual findings contained in them have enabled scientists to design better the software and evaluate existing programs, and to turn out valuable products based on a considerable body of valid knowledge.

One such product is the self-instructional course in the OTC (Operational Test Capability) Query Language for the computer in System 473L — the Headquarters USAF Control System. This course is not only designed to teach, but to maintain and advance the operator's proficiency in the

various ways of communicating with the computer. It has been thoroughly tested and is being successfully used in the field. In addition, because of its effectiveness, it will soon be used in six other Air Force Commands which use the same communication process.

Late in 1963, DSL completed research which suggested a programed learning approach to training technicians in the maintenance of AN/FST-2 equipment. The AN/FST-2 (Coordinate Data Transmitter) transmits quantized radar data free of both clutter and undesired radar returns from ADC Long Range Radar Sites to SAGE direction center, and SAGE depends heavily on these data to maintain its around-the-clock surveillance. DSL monitored a contractor's production of a text and diagrams to train technicians to trouble-shoot the system and isolate a required replaceable part. The training materials follow the Job Proficiency Guide format which the Air Force has adopted, and reflect the latest equipment configuration of the AN/FST-2.

The PERT Cost programed instruction text is another valuable contribution. DSL scientists provided extensive consultant support during every step in the development of this course. PERT (Program Evaluation Review Technique) is a management tool widely used throughout the Department of Defense and in industry, and is designed to aid high level managers in evaluating the progress of a program efficiently. It is a complicated technique which requires considerable time to learn when presented as a course. Since the objective of such a program was to allow busy managers to be freed for other duties, DSL some years ago developed an automated training course called PERTeach which permits the manager to learn the technique at his own rate. He can spend as much time in learning at one sitting as his other duties will permit, thus saving him from having to attend a lengthy lecture course. The PERT Cost instruction course builds on the learner's knowledge of the PERT system and teaches him to analyze program costs. Both PERTeach and PERT Cost courses are bing used in the Department of Defense PERT Orientation and Training Center and as on-the-job training aids throughout DOD.

DSL has given consultation on training problems to many other agencies such as the Air Force Ballistic Missiles Division, Industrial College of the Armed Forces, Air Training Command, Office of the Assistant Secretary of Defense (Manpower), Defense Communication Agency, Federal Job Corps, Office of Naval Research, and various defense contractors.

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Communications

In the most general terms, the objective of any Air Force information system is to facilitate operational decisions by commanders and controllers. Information transmitted through such systems, however, becomes useful only when it is presented to human beings for interpretation and action. The problem which generated studies in communications is twofold: first Air Force operations depend to a critical degree on information transmitted vocally. But command and control personnel often require more information than they can get quickly through direct talker-listener channels. To complicate the problem, telephone and radio communication systems may have technical faults which impair intelligibility. Second, although the computer can be the mainstay of the commander, it will be of little use in the decision-making process if it yields or accepts information too slowly, too quickly, or in a form hardly useable by man. So "communications" here are of at least two different kinds: communication between one man and another, and communication between men and computers. The greater part of the discussion here centers on the acute need to make efficient use of human speech and auditory perception, although there is an equally acute need to exploit the communicatory potential of the computer. Progress in man-computer communication is discussed later under Support of the Automated Laboratory.

Objective. Research in voice communication aims to identify and describe the features of auditory signals which operators and decision-makers can use for rapid, efficient, and unambiguous communication in an information system environment. A related effort is to improve methods for assessing radio and telephone system performance and diagnosing technical faults.

The objective of research in man-computer communication is to develop techniques for permitting real-time interaction between commander and computer components. DSL is working toward providing the commander with a computer language which is flexible and efficient, but does not require the constant intervention of a professional programmer. There is

a related effort to meet the need of command and control personnel to be able to update the computer's data files rapidly and simply determine whether information is being fed into storage from one source or a number of sources simultaneously.

Approach. Research in voice communication continues to explore the effects of radio and telephone system characteristics on man's ability to extract meaningful information from speech signals, and to refine techniques for measuring intelligibility. Exploratory development research is also being conducted into determining the communicatory value of non-speech information such as cues, independent of message content, by which listeners judge such factors as the identities and emotional states of talkers. Identifying the psychological and behavioral parameters that differentiate individual talkers and indicate emotional states has a variety of implications for the decision-making process. It could also have application to such exotic equipment as the vocal address computer of the future.

To achieve faster and more flexible communication between command decision personnel and the computer, programing techniques are being developed and refined which will permit the use of natural English (as opposed to cryptic machine language) to retrieve information from machine storage, and which will permit several human communicators at one time to query the computer or to update its data files.

Progress.

There have been several efforts to minimize the problems created by technical faults in voice communication systems, some of which are summarized below.

(1) Technicians in the field have for some time been using the Modified Rhyme Test (MRT) a brief, reliable, talker-listener test of speech communication systems — to measure the intelligibility of speech transmitted over a system to diagnose technical faults, and indicate overall handling capacity

under operational conditions. DSL scientists have been working continuously to make it even more reliable and to expand its usefulness. Series of experiments were run to establish its chief virtues over similar tests, to determine the feasibility of combining speech intelligibility and speaker identification tests, to compare MRT scores with other intelligibility test scores when the technicians are under various types of stress, and to determine the influences of the test response form and learning on test scores.

(2) A speech Communication Index Meter (SCIM) has also been in the field for some time. This electronic instrument measures the speech handling capacity of a voice communication system reliably, quickly, and automatically by analyzing sound patterns recorded on tapes and then played over the system. DSL has been working to improve SCIM's usefulness in a number of ways: two acoustic couplers were developed so that the microphone and headset portions of the system could be tested. The usefulness and accuracy of the device for testing systems under almost steady-state noise was demonstrated. Testing time has been shortened from three minutes to a few seconds.

(3) DSL provided direct support of system 484N (Wetwash), the Pacific Area Communication System. The laboratory provided the System Project Office several input tapes which were played over the system. The recorded results were later analyzed for intelligibility and a report was sent to the SPO.

Efforts to identify the range of physical and psychophysical parameters of the human voice are important because the results may well increase the voice-carrying potential of existing communication systems and affect design principles for those of the future. The design and realization of vocal address computers will also depend on such knowledge because a single electrical signal must be generated by <u>any</u> voice articulating the same word. Some recent work in this field follows:

(1) Several methodological studies were conducted to ascertain which approach would likely be the most productive.

(2) Several versions of an AB X type talker recognition test were developed. This procedure involves presentation of a sample of speech from speaker "A", a sample from speaker "B" and then a sample from speaker "X" whicn must be identified by the listener as either that of "A" or "B". Data from experiments using the final version indicates that an average of 64.8% correct identification can be achieved over a wode range of test conditions.

DSL's innovations in computer programing techniques and the possible implications for Air Force information systems are discussed in Support of the Automated Laboratory.

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## Applications

"Applications" are at the opposite end of the mission effort continuum from exploratory or advanced development projects, or "pure research." They are the tangible results of DSL's labor, the work and products put to use, the knowledge derived from painstaking research put into practice in the field.

Objective. The principle is simple: the process is first to theorize, then to verify experimentally and finally to put into practice. But it is hard to imagine the complexity and amount of work lying behind, for example, the type of lettering used in a certain display, let alone what the message should say to best accomodate the human user. Any product or consultation given the Air Force is backed up by many hours of testing, re-testing, experimenting, collating and analyzing data, as well as by the special capabilities of the scientists who design the product or give the opinion. The objective of the applications part of the mission effort is ultimately the objective of all the work done at DSL; to apply the principles and techniques developed through research to systems and situations in the "real world."

Approach. Some of the items included here have been mentioned earlier in other connections, but all of them involve direct support of planned or existing systems. The work includes such things as insuring that operator functions are properly allocated, designating personnel and training requirements, programing instruction, and testing and evaluating personnel subsystems. Some of the work is of a consultative nature, but it includes some development of "hardware" (such as SCIM — Speech Communication System Index Meter) and "software" such as the PERT COST course and the Rhyme Test described earlier.

Progress. Because of the disparate nature of the work, a bibliography or reports in the area of applications must necessarily be small compared to all the work which can be thought of as being applied. A great deal of it is in the form of letters, informal conversations, and consultations with

contractors who build the hardware and with the epole who use the systems already in operation. To indicate the depth and scope of contributions to the "real world", a brief description of some of the work is appropriate here.

(1) DSL is giving a wide range of support to the National Military Command Center (NMCC). Human factors studies have been made which contributed to the designing and implementing of the current configuration; scientists made a complete study of the NMCC to determine user needs which could be assisted by DSL; detailed descriptions of recommended action were made in the human factors and display areas; DSL personnel contributed to the designing, specifying, purchasing, installing, and testing of several displays and associated controls; several maintenance and operators' manuals were written.

(2) A number of DSL scientists were members of the Human Engineering Panel and Personnel and Training Panels of the AFSC Personnel Subsystem Working Group. Several reports were submitted, a number of contributions were made to MIL-STD-803 series manuals, Aerospace Human Engineering, and several other AFSC documents were rewritten to align them with the latest developments in human engineering.

(3) DSL was represented on a team of scientists responsible for formulating and defining possible communication experiments to be conducted first in the ESD/Mitre Simulation Laboratory, and subsequently aboard the future Manned Orbital Laboratory (MOL). A formal proposal was submitted.

(4) DSL voice communication scientists conducted speech intelligibility tests of Wetwash A, the Pacific Area Communications System, and submitted a report of findings. (See Communications)

(5) Consultation services were provided and a report submitted to ESD's Computer Division on the Man-Job-Match Computer Model Study.

(6) One scientist invented and produced a slide rule on which the subject in an experiment can record his "belief state," a mathematical

statement reflecting his reaction to evidence during certain kinds of decision-making experiments. The subject in a multiple choice situation distributes a quota of points over the alternatives in such a way as to indicate the strength of his belief in the correctness of each choice. The slide rule further prevents him from distributing more than an allotted quota of points over the alternatives.

(7) Human factors support was given to a working group charged with developing a proposal for a new ESD organization which would provide improved system design capability, and a report describing the structure and mission of the proposed organization was prepared.

(8) DSL monitored the production of automated training courses in the OTC Query Language for the Headquarters USAF Control System, in the maintenance of the AN/FST-2 Coordinate Data Transmitter, and in PERT/Cost. (See Programmed Teaching and Automated Training.)

(9) DSL is continuing to work with the Mitre Corporation in a project dealing with display problems in ESD L-Systems.

(10) Human factors and display problems support was afforded to the 492L System (USSTRICOM Command Center Improvement Program), the 466L System (development of display requirements for SIGINT the Air Transportable Signal Intelligence System), the 441L System (The AN/FPS-95 Radar Display Subsystem), Preliminary Design Review Board for the AN/FPS-85 Radar System, the 493L System (VOCOM) during Category I testing, the 416N SLBM (Surface Launch Ballistic Missile) Program, and the 416M BUIC (Back-up Interceptor Control) Program during Category II testing.

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Support of the Automated Laboratory

DSL's PDP-1 digital computer is the nerve center of what has come to be called its "Automated Laboratory Facility." The computer is small, rapidly operating, and expandible, and is being used extensively as a stimulus generator and data collector, processor and evaluator. It really affords two major advantages. (1) It greatly increases efficiency in that it saves time, conserves manpower, and affords perfect standardization of experimental conditions. (2) It permits kinds of experimentation not possible with conventional techniques. Experiments themselves can be dynamic, e.g., the character of the next stimulus presentation can be made to be a function of the sequence of responses preceding it.

The computer has been greatly expanded over the last two years, thus increasing its potential. With the expansion, though, increased complexity has also been added. In order to realize the effectiveness of such increased potential, part of DSL's total effort is in the form of technical support to task and project scientists.

Objectives. DSL's Automated Laboratory Division scientists undertake to develop computer techniques and routines which will make experimentation easier and more efficient, and facilitate programing for text preparation, editing, storage, and retrieval.

As hardware and software become more complex, there is an increasingly obvious need to document existing and new programs. There is a corresponding effort to write up these holdings and advances in an easy to understand form and to make them readily available to the user. Such is constantly being accomplished.

Approach. The many faceted problems are approached by forseeing as fully as possible the laboratory's programing needs, and by working as closely as possible with experimenters in developing programs and equipment as needed.

Progress. As indicated above, support of the automated laboratory facilities takes several different forms. A summary of some recent accomplishments follows.

(1) Work done on hardware used in in-house experiments and field projects includes: several modifications of the Forced Choice Four Interval Stimulus-Response Facility in ESD's anechoic chamber; setting up two speech intelligibility testing facilities; the assembly and thorough testing and adjusting of equipment for speech intelligibility testing in the field; setting up a photo laboratory which now produces slides, copy, and good quality visual materials as needed; building a self-contained unit which houses an automatic computer-controlled camera for making clear photographs of the computer scope-face up to the rate of two per second and several thousand in number; and allows for the operation of various auditory, light, and vibrotactile stimulus generators.

(2) A concerted effort is nearing completion to document the automated laboratory system, i.e., to produce up-to-date reference documents on the laboratory's hardware and software system so that new users who are not professional programers can quickly become familiar with the computer and the major features of the DSL programing system.

(3) Another major effort to increase the computer's usefulness is the development of a matrix algebra interpreter package (MAP) and a command language for use with it. This package will allow a real time interaction of scientist and computer in formulating and solving classes of mathematical problems which are widely applicable in both physical and behavioral sciences, and which are prohibitively complex without recourse to a computer. As an adjunct to the algebraic interpreter, a system will be developed which will decode alphanumeric strings composed of algebraic operators and arbitrarily labeled variables, recording them in appropriate sequences of calls to MAP procedures. The interpreter will provide the user scientist with real time access to powerful analytic tools without imposing demands on him. He will have to be familiar only with a reasonably standard algebraic notation and a few simple rules for exercising input-output options. The system should be ready for use very soon.

Relevance for Air Force Systems

Although it appears that the innovations in programing techniques described here have meaning only for laboratory experimenters, some of them evolve as products which are directly applicable to information systems. Whenever a commander, controller, or operator faces a computer which yields or accepts information in a cryptic form, the system's function, to facilitate the decision-making process, breaks down. DSL's efforts to provide computer programs and communication techniques for experimenters do, in fact, have application outside the laboratory environment. New and more efficient techniques for retrieving information from document collections are currently being field tested in an operating environment with the cooperation of NASA. A statistical analysis of language regularities is being run to test an assumption about the distributions of synonyms in text. Verifying this assumption would validate and give insight into the methods used in most operating information retrieval systems, and may lead to methods for handling semantics in text. DSL plans in the near future to consider techniques for implementing self-extending computer languages using the computer display scope and light-pen. A self-extending language is one to which definitions of new operations can be added, and such a capability would give users an important increase in flexibility.

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13. ABSTRACT

This report summarizes the activities of the Decision Sciences Laboratory and describes achievements, progress, results obtained by the Laboratory scientists in the past two years.

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